

P-3
Dense Gas and HII regions in the Starburst Galaxy NGC 253J.E. Carlstrom (U. C. Berkeley), J. Jackson (MPI), P.T.P. Ho (CfA),
and J.L. Turner (U.C.L.A.)

The energetic activity in the nuclear barred region of NGC 253 is attributable to a burst of star formation. NGC 253 is in many ways a twin of the 'prototypical' starburst galaxy M82; the strong non-thermal radio continuum, high far-infrared luminosity, and bright molecular emission of the central 1 Kpc parallel the morphology of the M82 starburst. Furthermore, the filamentary low ionization optical emission and extended X-ray emission along the minor axis in NGC 253 is similar to a scaled down version of the well developed galactic bipolar wind in M82. The infrared luminosity of NGC 253, $3 \times 10^{10} L_{\odot}$, is comparable to M82 but is emitted from a smaller region (Telesco and Harper 1980). This suggests that the NGC 253 starburst may be more intense and at an earlier evolutionary stage than M82. However, the presence of a non-stellar AGN in NGC 253 may complicate the comparison (Turner and Ho, 1985).

We used the Hat Creek millimeter interferometer to map emission from the $J = 1 \rightarrow 0$ transitions of HCN and HCO^+ , as well as 3 mm continuum emission, toward the nuclear region of NGC 253. The HCO^+ and continuum observations are sensitive to spatial scales from 6" to 45". The 2' field of view comfortably includes the entire starburst region (about 40"; 650 pc). Because the longer baseline HCN observations are not yet complete, they are only sensitive to spatial scales from 15" - 45".

The HCN and HCO^+ emission trace high density molecular gas ($n(\text{H}_2) > 10^4 \text{ cm}^{-3}$). Therefore the similar distributions of the HCO^+ emission (see figure 1), the HCN emission (not shown here), and the bright CO emission (see figure 1 in Canzian *et al.* 1988) suggests that the molecular gas associated with the starburst is dense. Although not resolved in the integrated emission map, the spectra (see figure 1) and the position velocity map in figure 2 reveal two components of dense gas. The two velocity components are separated by approximately 9" (~ 140 pc in projection). The emission centroid is coincident with the nucleus and the base of the X-ray emission (see figure 1). The two components are most easily explained as limb brightened emission from a torus of dense gas similar to the molecular circumnuclear ring inferred for M82. However, the molecular ring in NGC 253 is much smaller than the ring in M82 (140 pc vs. 400 pc).

The 3.3 mm continuum emission, resolved by the interferometer observations (see figure 3a), is confined to the heart of the starburst region. As in M82 (Carlstrom 1988), the 3.3 mm emission is distributed similar to emission at longer wavelengths which are dominated by nonthermal emission. The continuum emission in both galaxies peaks at the base of the optical filamentary emission and X-ray emission and appears to be 'bracketed' by dense molecular gas (see figure 3b). The 3.3 mm flux (0.35 ± 0.05 Jy) sets an upper limit to the thermal free-free emission from HII regions. Although thermal emission from dust is a small fraction of the 3.3 mm flux, the contribution from non-thermal emission is not presently known. The ratio of the infrared luminosity to Lyman continuum luminosity ($N_L = 4.7 \times 10^{53} \text{ s}^{-1}$ for $S_{ff} = 0.35$ Jy at 3.3 mm) for NGC 253 is twice the ratio measured for M82 (Carlstrom 1988). This suggests that the HII regions may be less evolved in NGC 253 with dust competing effectively for the ionizing photons. Alternatively, lower mass stars may be relatively important in NGC 253, supplying more non-ionizing luminosity.

The observations also support the evolutionary scenario of starbursts suggested by several authors and recently outlined by Rieke *et al.* (1988). In this scenario NGC 253 is at an earlier evolutionary stage than M82. Superbubbles of the thermalized ejecta of numerous supernovae have broken out of one of the poles of the galaxy disrupting the molecular clouds. Within the plane of the galaxy, a portion of the kinetic energy has compressed and pushed the molecular clouds out of the very center forming a dense molecular torus. Further evidence for this evolutionary scenario is given in Rieke *et al.* (1988).

Although a considerable number of observational investigations have focussed on the state of the interstellar medium of the starburst region in M82 and it is now fairly well understood, the relevance of this knowledge to other starburst galaxies has been debated. The high resolution observations of NGC 253 presented here demonstrate that M82 is not unique.

This work was supported by NSF grant AST87-14721.

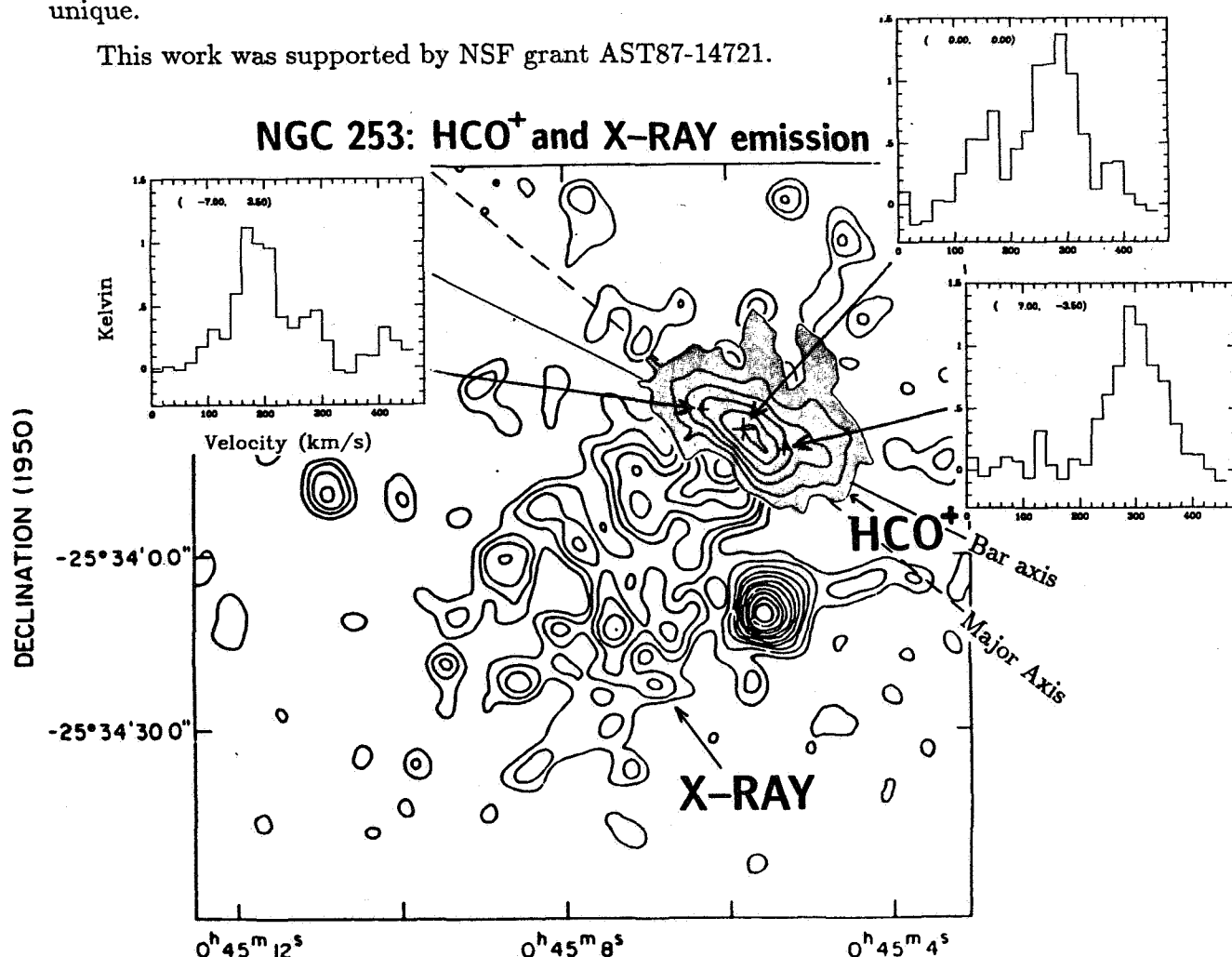


Figure 1. The HCO⁺ $J = 1 \rightarrow 0$ integrated emission plotted on the X-ray map of Fabbiano and Trinchieri (1984). The HCO⁺ emission contours are multiples of $13.5 \text{ Jy} \cdot \text{km s}^{-1}$ per beam. The synthesized beam is $10.8'' \times 7.0''$. The solid line marks the position angle of the major axis and the dotted line marks the position angle of the stellar bar (Scoville *et al.* 1985). Note that the dense molecular gas tends to 'bracket' the base of the X-ray emission.

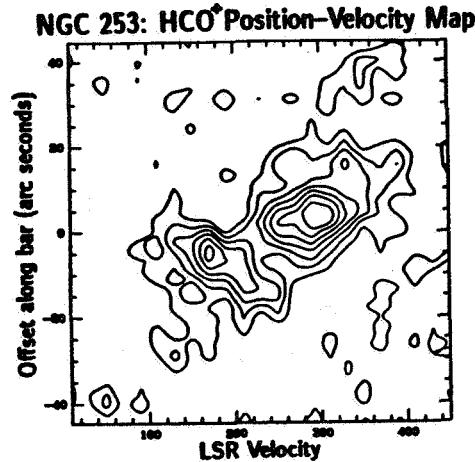


Figure 2. A position velocity map of the HCO^+ emission. The cut is along the major axis. The nucleus is at $0''$. Note that the HCO^+ emission is from two separate velocity components spatially separated by $\sim 9''$.

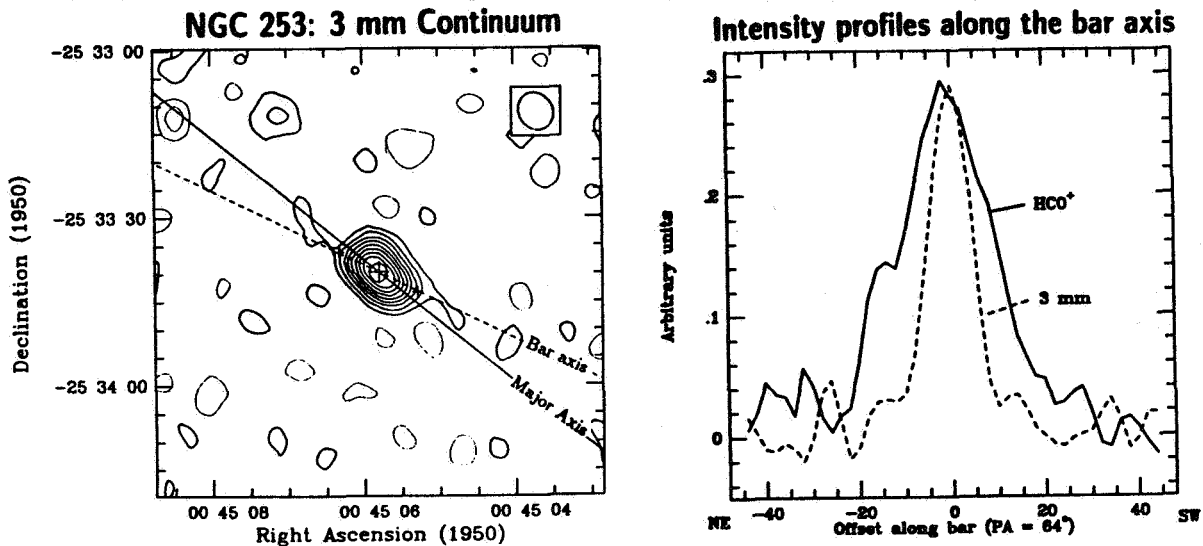


Figure 3. (a) The 3.3 mm continuum map. The contour interval is 18 mJy per beam. The beam, $7'' \times 6''$, is shown in the upper right corner. The cross marks the position of the nucleus. The total flux is 0.35 ± 0.05 Jy. (b) Comparison of the distribution along the major axis of the HCO^+ emission (solid line) and the 3.3 mm continuum emission (dashed line).

References:

- Canzian, B., Mundy, L. G., Scoville, N. Z. 1988, Ap. J., **333**, 157.
 Carlstrom, J. E. in "Galactic and Extragalactic Star Formation" ed. R. E. Pudritz and M. Fich, Dordrecht: Reidel, 1988.
 Carlstrom, J. E., 1988, Ph.D. Thesis, University of California, Berkeley
 Fabbiano, G., and Trinchieri, G. 1984, Ap. J., **286**, 491.
 Rieke, G. H., Lebofsky, M. J., and Walker, C. E. 1988, Ap. J., **325**, 679.
 Scoville, N. Z., Soifer, B. T., Neugebauer, G., Young, J. S., Matthews, K., and Yerka, J. 1985, Ap. J., **289**, 129.
 Telesco, C. M. and Harper, D. A. 1980, Ap. J., **235**, 392.
 Turner, J. T., and Ho, P. T. P. 1985, Ap. J. (Letters), **299**, L77.